【Grant-in-Aid for Scientific Research (S)】

Broad Section B

Title of Project : Nucleosynthesis under the extreme conditions in the universe

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【Purpose and Background of the Research】

There is a close relationship between the universe with a vast spread more than 10^{26} m and atomic nuclei with extremely small radii of ~ 10^{-15} m. There was no element at the beginning of the universe, but various elements exist in the present universe. All the elements have been synthesized by nuclear reactions in the 13.8-billion-year history of the universe.

One of the most important reactions in the nucleosynthesis in the universe is the triple alpha (3α) reaction. In the 3α reaction, ^{4}He (α) is captured by ^{8}Be, which is a resonance state of two α particles. However, the 3α reaction rate in an extreme environment such as high temperature and high density might increase several to 100 times compared to the known value.

In the present project, we aim to determine the 3α reaction rate in an extreme environment and clarify the nucleosynthesis in the universe.

【Research Methods】

As shown in Fig. 1, 3α resonance states are formed as intermediate states in the 3α reaction. Most of these 3α resonance states decay back to 3α particles, but a tiny fraction of the resonance states decay to the ground state to synthesize ^{12}C. In order to determine the 3α reaction rate, it is necessary to measure the decay probability of these 3α resonance states to the ground state.

<u>3α reaction rate at high temperature</u>

The 3α reaction at normal stellar temperature (10^8 K) mainly proceeds through the 0^+_2 state, but the 2^+_2, 3^-_1 and 0^+_3 states with higher excitation energies play important roles at higher temperature than 10^9K. Although the decay probability of the 0^+_2 and 2^+_2 states to the ground state are already known, those of the 3^-_1 and 0^+_3 states have never been measured so far because those are extremely low (10^{-6}—10^{-8}). Therefore, we will measure the inelastic α scattering from ^{12}C under inverse kinematical conditions to determine the decay probabilities of the 3^-_1 and 0^+_3 states to the ground state.

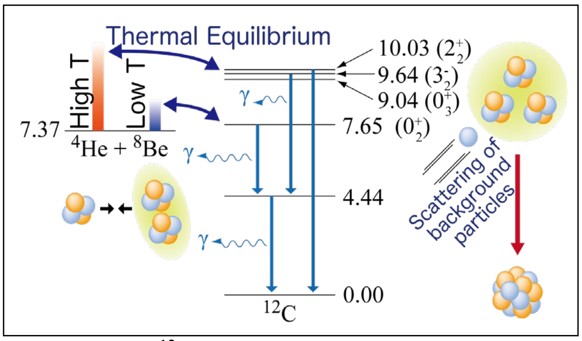

Figure 1 Triple alpha reaction

<u>3α reaction rate at high density</u>

In the normal 3α reaction, the 3α resonance state formed as an intermediate state decays to the ground state by emitting γ ray. On the other hand, in a high-density environment, endothermic inelastic scattering of background particles enhances the de-excitation of the 3α resonance states to the ground state. Especially, the contribution of the inelastic scattering of neutron is dominant. It is, therefore, necessary to measure cross sections of inelastic neutron scattering from the 3α resonance states, but it is impossible to measure the cross sections because lives of the 3α resonance states are very short.

In the present project, we will measure the cross section of the time-reversal reaction instead of the normal reaction to de-excite the 3α resonance states. The cross sections of the normal reaction can be determined from the time-reversal reaction using the detailed balance principle. However, it is not easy to measure the cross sections of the time reversal reaction because energies of the 3α particles emitted from the reaction are quite low (< 0.5 MeV). To detect such low- energy α particles, we will develop a new active target system.

【Expected Research Achievements and Scientific Significance】

The 3α reaction rate is a very important parameter to clarify the nucleosynthesis in the universe. For example, high-temperature and high-density ^{4}He phases emerge in the gravity-collapsed supernova and heavy-element synthesis is ignited by the 3α reaction. Therefore, the abundance of heavy elements drastically changes if the 3α reaction rate increases. If the 3α reaction rate in an extreme environment is determined by the present project, theoretical predictions of heavy element abundances are improved and provide an insight into mechanisms of supernova explosions, which still remain unclear.

【Publications Relevant to the Project】

S. Wanajo et al., Astrophys. J. 729, 46 (2011).
M. Beard et al., Phys. Rev. Lett. 119, 112701 (2017).

【Term of Project】 FY2019-2023

【Budget Allocation】 132,600 Thousand Yen

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